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OTTAWA October 30th, 1942.

REPORT

of the

ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1319.

Hardenability of 60-mm. Armour Plate (Dominion Foundries and Steel), and its Relationship to Ballistic Limit.

(This is Report No. 7 of the Canadian Bureau of Mines 1942 Armour Plate Statistics Series.)

(Copy No. 9.)

BUREAU OF MINES
DIVISION OF METALLIC MINERALS

ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

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Foreword.

This report is based on data submitted by the Dominion Foundries and Steel Limited, Hamilton, Ontario. Previous reports in this series* have discussed methods of analysing industrial data and examples of armour plate data have been given. Results and conclusions contained herein

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* See list at foot of Page 2.

(Foreword, cont'd) -

are applicable only to the source from which they are drawn and it should not be inferred that they are of general application.

The report deals with the method used and the results obtained. The appendix gives some additional data which are of interest only to those wishing to follow the statistical technique.

It is assumed that all ballistic limit results are correctly reported and that 2-pound shot are standard projectiles for the test.

Canadian Bureau of Mines 1942 Armour Plate Statistics Series:

(1) No. 1144: Armour Plate Improvement As Related to Statistical Analysis of Manufacturing Data. (January 9th, 1942).

(2) No. 1157: Armour Plate Quality and its Relation to Chemical and Physical Tests. (February 12th, 1942).

(3) No. 1163: Statistical Analysis of Armour Data, Applied to the General Steel Castings Corporation. (February 14th, 1942).

(4) No. 1166: A Statistical Analysis of 60-mm. Armour Plate from the Dominion Foundries and Steel Limited. (May 1st, 1942).

(5) No. 1298: Dominion Foundries and Steel Limited 60-mm. Armour Plate Ballistic Limit Test Results Presented in Quality Control Chart Form. (September 19th, 1942).

(6) No. 1299: Variation in Results of Physical and Chemical Tests on Steel. (September 24th, 1942).

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Hardenability; Grossman's Method:

Recent work by Marcus A. Grossman[*] has greatly simplified the complex subject of alloys and their effect on iron. It is now possible to express in one figure the summation of the effects of all the elements on the final hardening property of the metal.

In Grossman's system, each of the following is assigned a factor:

Grain size }	Sulphur	Vanadium
Carbon }	Nickel	Boron
Manganese	Chromium	Aluminium
Silicon	Molybdenum	
Phosphorus	Copper	

The product of all the factors is the hardenability number of the steel. This number is the diameter of the bar which will harden to a half-martensitic structure at the centre.

Application to D. F. & S. 60-mm. Armour:

In applying Grossman's method to the data supplied by Dominion Foundries and Steel Limited, the following system was adopted:

Since grain size, aluminium, boron, copper, vanadium and titanium were not reported, their effects were assumed to be constant. As a result, the hardenability figures give only an approximation of the true result.

The factors adopted for carbon, chromium and silicon were as follows:

(Continued on next page)

[*] Tech. Publication No. 1437, A.I.M.E. 1942.

(Application to D. F. & S. 60-mm. Armour, cont'd) -

Carbon.

Carbon, per cent	Factor	Carbon, per cent	Factor
.20	.166	.36	.220
.21	.170	.37	.223
.22	.174	.38	.226
.23	.177	.39	.229
.24	.181	.40	.232
.25	.185		
.26	.188		
.27	.192		
.28	.196		
.29	.199		
.30	.202		
.31	.205		
.32	.209		
.33	.212		
.34	.215		
.35	.218		

Chromium.

Chromium, per cent	Factor
.10	1.235
.20	1.470
.30	1.705
.34	1.800

Above .34 chromium, the following equation was used:

Factor = 1.000 + .0117 Cr.

Silicon.

Silicon, per cent	Factor	Silicon, per cent	Factor	Silicon, per cent	Factor
.15	1.135	.27	1.243	.40	1.35
.16	1.144	.28	1.252	.45	1.395
.17	1.153	.29	1.261	.50	1.44
.18	1.162	.30	1.270	.55	1.46
.19	1.171	.31	1.279	.60	1.48
.20	1.180	.32	1.288	.70	1.515
.21	1.189	.33	1.297	.80	1.55
.22	1.198	.34	1.306	.85	1.565
.23	1.207	.35	1.315	.90	1.58
.24	1.216	.36	1.325	1.00	1.61
.25	1.225	.37	1.329	1.20	1.64
.26	1.234	.38	1.336	1.40	1.67
		.39	1.343		

For the other elements, a straight-line relationship

(Application to D. F. & S. 60-mm. Armour, cont'd) -

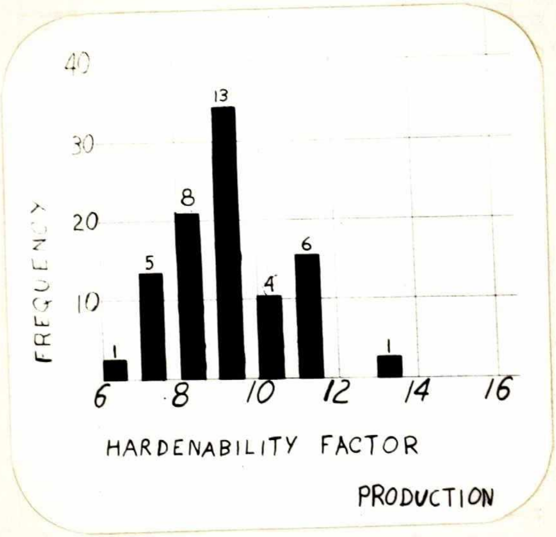
was assumed:

Sulphur factor	=	1.000 - .0014 S
Phosphorus factor	=	1.000 + .0025 P
Nickel factor	=	1.000 + .00364 Ni
Molybdenum factor	=	1.000 + .032 Mo
Manganese factor	=	1.000 + .039 Mn

Frequency Distribution:

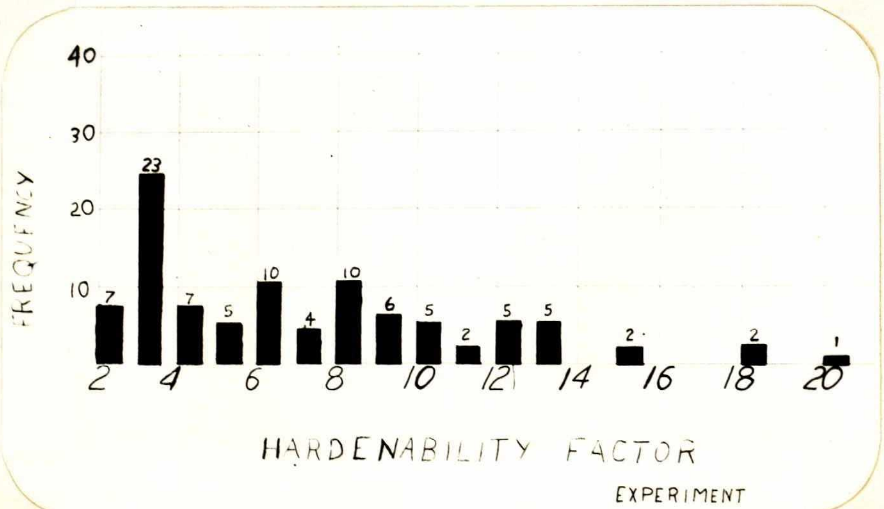
Production plates are those submitted for acceptance tests representing normal production. Experimental plates do not represent the regular product.

Figure 1.



Distribution of Hardenability of Production Plates.

Figure 2.



Distribution of Hardenability of Experimental Plates.

(NOTE: The number above each bar in the above figures indicates the actual number of results recorded.)

Correlation between Hardenability and Ballistic Limit:

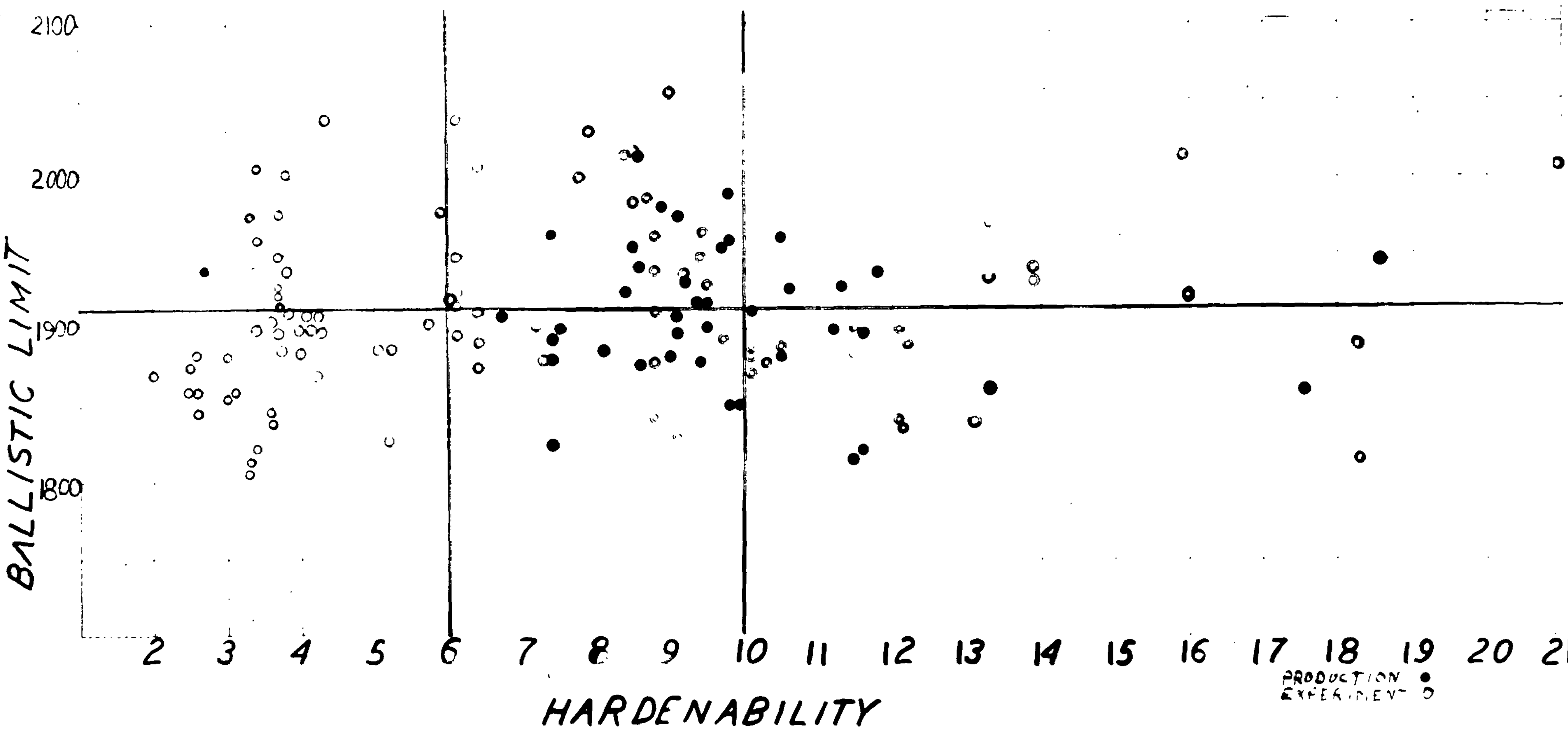
Page 7 (photostat) shows the relationship between ballistic limit and hardenability.

It is of decided interest to note that a wide range of alloy content affects the ballistic limit only slightly.

The hardenability - ballistic limit relationship is shown more clearly on Page 8 (photostat), using the charting method described in previous reports.

(Pages 7 and 8, following, are photostats, foolscap size)

- (Text is resumed on Page 9) -



2100
2000
1900
1800
BALLISTIC LIMIT
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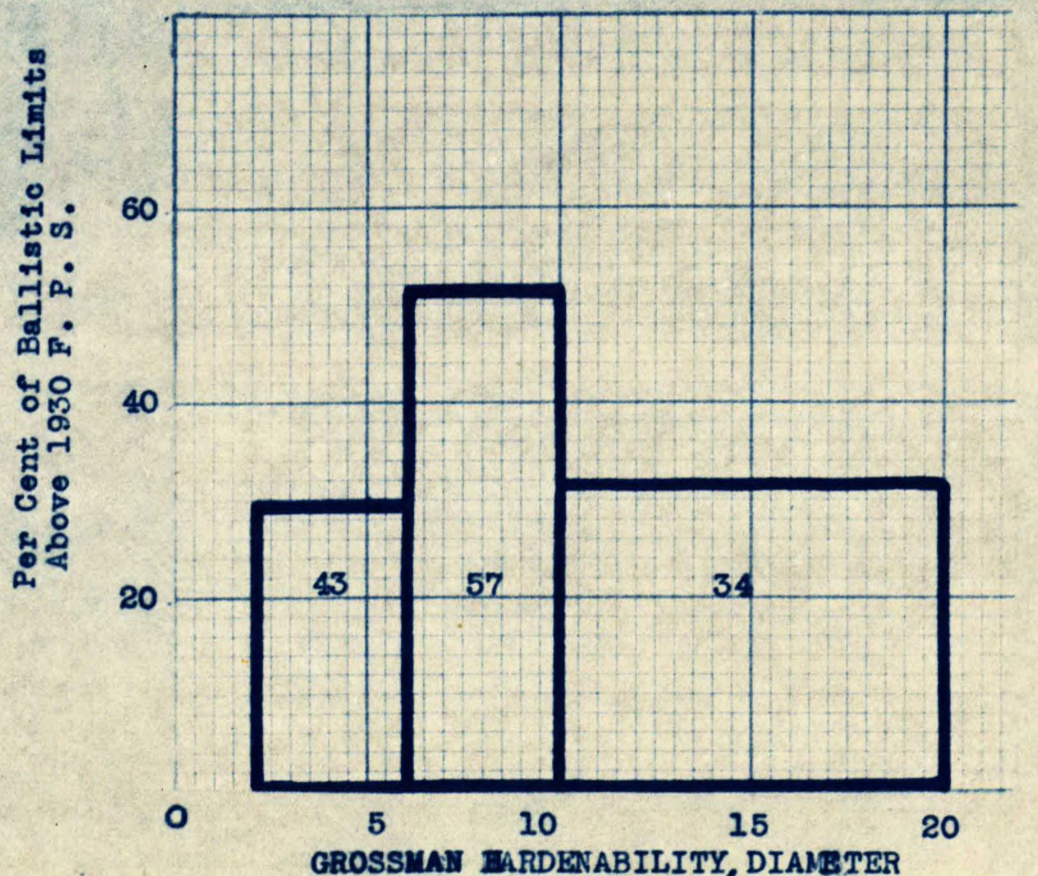
19
20
21
HARDENABILITY
PRODUCTION ●
EXPERIMENT O

HARDENABILITY RELATED TO BALLISTIC LIMIT

60 mm D. F. S. Plate Experiment 1-100

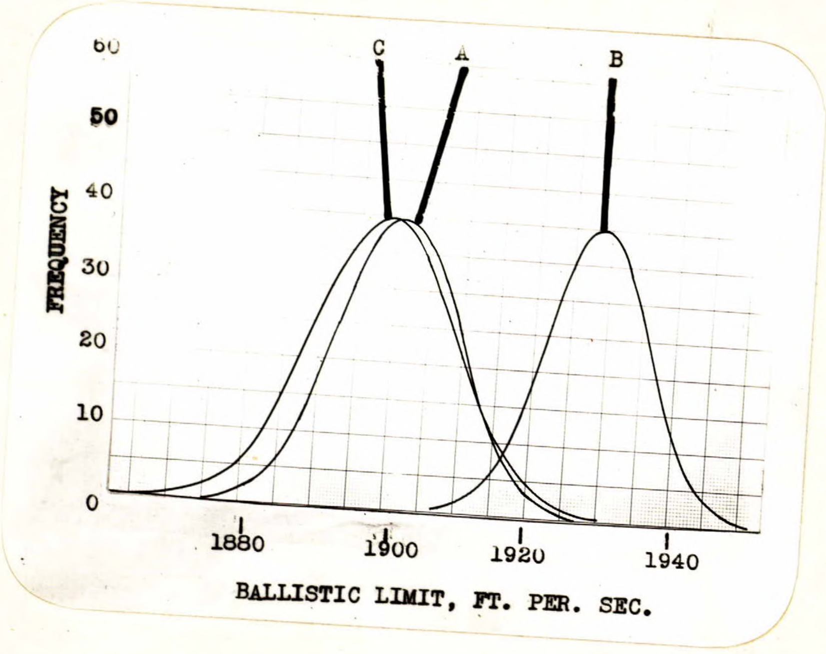
Production 1- 43



(Correlation between Hardenability and
Ballistic Limit, cont'd) -

Another way of showing the effect of hardenability is shown in Figure 3. This chart is drawn from an analysis of the distribution of results in each hardenability group.

Figure 3.



BALLISTIC LIMITS OF DIFFERENT HARDENABILITY GROUPS.

A. - Probable curve of distribution of means of samples of 43 results having hardenability between 2 and 5.9.

B. - Probable curve of distribution of means of samples of 57 results having hardenability between 6 and 9.9.

C. - Probable curve of distribution of means of samples of 35 results having hardenability between 10 and 21.

General Discussion:

The adverse effect of high alloy content has been pointed out previously in this series of reports. It is assumed that the high alloy metal tends to have a dendritic structure which normal heat treatment cannot break up. As hardenability is reduced, the metal becomes more and more homogeneous, until the best structure is obtained with a hardenability of 6 to 9.9 (assuming grain size 6, not counting the effect of boron, aluminium, vanadium, and copper).

It seems only reasonable to conclude that each of the inherent factors in the production of armour has its optimum range. If these factors are measured and recorded, statistical methods will point out the best range. This report has shown that hardenability has an optimum range.

It is hoped that by adjusting each of the many other factors involved, the highest possible quality of armour plate may be produced.

Conclusions:

UNDER THE PRESENT SYSTEM OF MANUFACTURE, -

(1) A DEFINITE RELATIONSHIP BETWEEN HARDENABILITY AND BALLISTIC LIMIT HAS BEEN SHOWN TO EXIST.

(2) BEYOND A CERTAIN POINT EXTRA ALLOY SERVES NO USEFUL PURPOSE. INSTEAD, IT RESULTS IN POORER ARMOUR.

(3) THE CONTROL OF HARDENABILITY WITHIN 6 TO 9.9 IS THEREFORE ADVISABLE.

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APPENDIX.

Characteristics of Distributions and Reliability of Differences.

Three groups of ballistic limits values were prepared for analysis.

Group A contained those plates with hardenability factors between 2" and 5.9" diameter.

Group B contained those plates with hardenability factors between 6" and 9.9" diameter.

Group C contained those plates with hardenability factors between 10" and 21" diameter.

The characteristics of the three distributions of data were:

	Symbol	Group A	Group B	Group C
Average or mean,	$\bar{X}$	1,901 ft./sec.	1,929 ft./sec.	1,899 ft./sec.
Standard deviation,	σ	54	53.6	58
Estimated standard deviation of population,	$\bar{\sigma}$	54.5	54	59
Standard error of mean,	$\sigma_{\bar{x}}$	8.31	7.15	9.97
Standard error of standard deviation,	σ_{σ}	5.94	5.06	7.06

Q. Could the difference in means of Groups A and B occur due to chance alone?

A. $$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma_{\bar{X}_1 - \bar{X}_2}} = \frac{1929 - 1901}{\sqrt{7.15^2 + 8.31^2}} = 2.56$$

If this difference is due to chance alone, it would be expected to occur only 104 times in 10,000. It is highly probable, therefore, that the observed

(Appendix, cont'd) -

difference is due to hardenability.

Q. Could the difference in means between Group B and Group C occur due to chance alone?

A. $$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma_{\bar{X}_1 - \bar{X}_2}} = \frac{1929 - 1899}{\sqrt{7.15^2 + 9.97^2}} = 2.45$$

If the observed difference in means is due to chance alone, then differences as great or greater than the observed difference would be expected to occur 142 times in 10,000; that is, the odds are 1 to 70 that this would happen. It is quite probable, therefore, that the observed difference is due to hardenability.

Q. Could the observed difference in means between Group A and Group C occur due to chance alone?

A. $$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma_{\bar{X}_1 - \bar{X}_2}} = \frac{1901 - 1899}{\sqrt{8.31^2 + 9.97^2}} = 0.154$$

If the difference in means is due to chance alone, then the observed difference, or a greater, would be expected to occur 9.881 times in 10,000. Therefore, there is no significant difference between these two groups.

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A great many so-called "experiments" conducted on war materials fail to take into account the phenomenon of variation. When the chart on Page 7 is examined, it can easily be seen that action based on interpretation of a few results may frequently be in error. In the case of finding the effect of hardenability on ballistic limit, it is necessary to be sure

(Appendix, concluded) -

that all possibilities of variation occurred in each hardenability group. This method of using the law of large numbers was first pointed out by Daeves.[1]

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(1) The Utilization of Statistics, a New and Valuable Aid in Industrial Research and in the Evaluation of Test Data - by Dr. Karl H. Daeves. Published in TESTING, March 1924.

Ottawa, Canada.
October 30th, 1942.
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